INTRODUCTION

While the United States invests more than Japan in research and development (R&D), Japan's R&D investments relative to the size of its economy are slightly larger than those of the United States. In 1994, for example, Japan invested 2.6 percent of its gross domestic product (GDP) in R&D compared with 2.5 percent by the United States. With a GDP that was only 39 percent of that of the United States ($2.1 trillion versus $5.3 trillion in constant dollar terms) in 1994, Japan's overall R&D expenditures were 41 percent of those of the United States—$54 billion versus $133 billion.[1] Japan's proportion of GDP invested in overall R&D began to surpass that of the United States in 1989 and has continued for several years. (From 1975–88, the United States invested a relatively larger amount in R&D than did Japan.) (See table A-1.)

Japan's effort in basic research, however, has been somewhat lower than that of the United States, but this area is currently receiving special attention in Japan. From 1976–88, Japanese spending on basic research, relative to the size of its economy, generally remained at about 80 percent of U.S. levels (Papadakis and Jankowski, 1991) and was conducted mainly in industrial laboratories. From 1980–92, average annual rates of growth in investments in basic science in Japan outpaced GDP growth rates by 5.9 percent versus 4.2 percent, respectively. By 1992, Japan's basic research expenditures reached about 84 percent of those of the United States, representing about 0.38 percent of GDP. In that same year, U.S. basic research expenditures represented 0.45 percent of GDP. While Japan has traditionally invested a smaller percentage of its overall R&D in basic research compared with the United States (table A-6), since 1992, Japan has adopted the goal of improving its basic research and innovation capacity—particularly in universities—through increasing government support of R&D.

To understand the context of this recent shift to focus on basic science, the development of Japan's science and technology (S&T) policy can be briefly summarized in three main phases: the well-known catch-up phase following World War II; the initiatives for innovative technologies in the 1970s following the oil crisis; and the new funding programs of the 1990s to change the culture of science in Japan and promote breakthrough research.

Following World War II, Japan rebuilt its economy by consciously investing in quality engineering to improve on imported technologies. From 1945–72, Japan successfully carried out a technology policy of importing Western technology and investing large amounts of R&D funding on adaptive technology (Tamura and Peck, 1983). Initially significant in this post-war development period were the policies of the Natural Resources Section[2] and the Scientific and Technical Divisions of the Occupation Forces. The latter played a key role in rehabilitating Japan's capacity for scientific inquiry (Yoshikawa and Kauffman, 1994). The process of catching up after the war included the selection of technologies developed overseas, long-term investment in adaptive research, and marketing of improved products. The Japanese government assisted in this catch-up phase, most notably by adopting trade policies that protected Japanese firms from competition and by restricting foreign investment in Japan (Odagiri and Goto, 1993, and Goto, 1995).

The serious environmental problems of the 1960s and the energy crisis of the early 1970s motivated Japan to advance to a second phase of S&T policy: building its capacity for indigenous and innovative technology for sustainable development. The Japanese S&T White Paper in 1973 began urging a restructuring of research toward this end. This S&T document provided a vision of a new focus for Japanese R&D—that of performing basic research related to the goals of developing environmentally sound technologies for the nation (Science and Technology Agency (STA), 1973). The ensuing 20 years saw a gradual evolution of science structures and the introduction of new programs for the support of innovative research, including a competitive grants-in-aid program in the universities, new mechanisms for funding young scientists from industry and universities on fixed-term appointments, and a redirection of national laboratories toward long-term basic research.

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[1] All dollar amounts in this report are in 1987 constant dollars using purchasing power parity (PPP) conversions. PPP conversion rates for Japanese yen are given in table A-1. PPPs are used to convert a country's national currency expenditures to a common currency unit that allows *real* international quantity comparisons to be made. PPPs are based on "market basket" pricing exercises. See Methodology and Notes on Data Series for details on why PPP conversions are preferable to market exchange rates.

[2] The Natural Resources Section of the Occupation forces reported on Japan's natural resources, as well as resource requirements for Japan to recover and advance to the highest economic level (Yoshikawa and Kauffman, 1994).

The third phase of S&T policy began in the 1990s with the growing awareness among Japanese S&T decision makers that continuing their formerly successful strategy of emphasizing research to adapt imported technology would not provide the capabilities required in new and rapidly developing technologies, such as biotechnology, gene therapy, and software for computer networks (Ichikawa, 1996). Competition from Asian emerging economies further increased Japan's awareness of the need for ever more advanced industries based on fundamental science.

In 1992, therefore, Japan's Cabinet called for a doubling of the government's R&D budget as soon as possible, and expanded funding of new programs and mechanisms for innovation research. The S&T policy document[3] of that year recommended a major renewal of facilities and equipment in the universities and national research institutes and an expansion of competitive research grants. Subsequently, in 1995, the Science Council of Japan created the legislative support to increase the science budget through the Science and Technology Basic Law. The S&T Plan of 1996 suggests that the government of Japan invest 17 trillion yen in R&D from 1996–2000, equivalent to $74 billion in 1987 constant dollars. This would represent a sizable increase (35 percent) over the amount spent in the previous five years—approximately $51 billion in constant dollars from 1991–95 (table A-4). To this end, the Japanese government increased its R&D budget in 1996 by 12.5 percent and the Cabinet-approved 1997 R&D budget has an additional 6.8-percent increase.[4]

Despite Japan's economic recession, the Science Council managed to generate unanimous support in the Diet to use the sale of construction bonds to increase science funding.[5] The notion of restructuring the economy through knowledge and education is widely held throughout the Japanese culture (Rohlen, 1992). Those Japanese over age 50 have lived through the reconstruction of Japan from devastation to become a leading world power. Those Japanese under age 50 are told repeatedly that in a country with few natural resources, education and S&T must be key national resources for prosperity.

The passage of this new Science and Technology Basic Law indicates that improving Japan's S&T capacity for innovative research is a national priority. Mobilizing strategic basic research is deemed essential for recovery from recession and for the long-term sustainable development of Japan. In the summer of 1996, the Science and Technology Basic Plan required national science agencies, as well as local governments, to submit 5-year plans on how they will accomplish this transition to a higher standard of S&T in Japan.

Although increasing the government science budget received unanimous support in the Diet, the tactic used to generate new research funding through the issuance of construction bonds remains controversial. The Science Council and the science community have argued that this investment in innovative research will yield breakthroughs for future industries, increasing the tax base and allowing repayment to the public for all the bonds floated. Japan's Ministry of Finance and some Diet members are concerned, on the other hand, about whether or not the bonds will be paid back in a timely manner (Ikeda, 1996).

A deeper concern is whether or not this new money will actually improve the quality of basic research and innovation. Research scientists and science policy decision makers alike cite the need to change the culture of science in Japan to provide a more competitive research environment and to increase human resources for science. (Kitazawa, 1996). Appropriately, the Science and Technology Basic Plan (July 1996) and the White Paper on Science and Technology (1996) focus on steps to be taken from 1996–2000 to improve the climate for basic research in Japan (STA, 1996).

This report provides comparisons of U.S. and Japanese science resources and some initial evidence that Japan is expanding the human and financial resources for science, while improving the environment for basic research. The data cover S&T trends in overall R&D from 1975–94 as well as more recent changes in government and university research in Japan. It also covers research trends in private industries and the training of personnel within Japanese companies and in American universities. The report concludes with the implications of these changes to the U.S. and international research community and the need for further research.

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[3] Basic Policy for Science and Technology (approved by the Cabinet, April 1992) based on the 18th Recommendation of the Council for Science and Technology (January 24, 1992), a report on the Comprehensive and Basic S&T Policy: Toward the New Century.

[4] Still pending Diet approval.

[5] The use of construction bonds required Ministry of Finance approval.

Highlights

National Research and Development (R&D) Patterns

- In the last two decades, both the United States and Japan have had strong growth in R&D, followed by slight annual declines from 1991–94.

- Japan's overall R&D investments are slightly larger than those of the United States. In 1994, Japan invested 2.6 percent of its gross domestic product (GDP) in R&D whereas the United States invested only 2.5 percent of its GDP. Japan's higher investment in overall R&D compared with that of the United States (relative to the size of its economy) began in 1989 and has continued for several years.

- In non-defense R&D Japan significantly outspends the United States relative to the size of its GDP. Japan has invested between 2.5 percent and 2.8 percent of its GDP in civilian research for the past 10 years. The United States has invested approximately 2.0 percent of its GDP in civilian R&D over the period from 1975–94. Defense R&D in the United States declined to 20 percent of overall R&D by 1994, from a high of 32 percent in 1987. In contrast, Japanese defense research is only 1 percent of overall R&D.

- In Japan, industry has historically funded a larger share of R&D than the government sector. In 1990, industrially funded research reached 78 percent of total R&D in Japan. By 1994, however, government support of total R&D reached almost 20 percent while industry support declined to 73 percent.

- The government of the United States has been a more significant source of support for R&D than that of Japan if defense R&D is included. U.S. government-sponsored research grew rapidly in the 1980s, peaked in 1987, and has since declined, following worldwide reductions in defense R&D since the late 1980s. U.S. Government support of overall R&D fell from 45.8 percent in 1985 to 35.0 percent in 1995.

Science and Engineering Personnel

- Japan has more engineers as a proportion of its overall labor force than the United States. In fact, relative to the size of its labor force, Japan has more engineers than any leading industrial nation except Sweden (NSF,1996c). This engineering concentration stems from the large number of engineering degrees earned at the undergraduate level in Japan (See section on Higher Education: undergraduate level).

- The stock of scientists and engineers relative to the labor force is sharply increasing in Japan but only moderately so (for scientists) in the United States. The Japanese stock of scientists and engineers grew 8.0 percent annually from 1985–90. In contrast, in the United States the stock of engineers remained stable between 1986 and 1991, at 146 per 10,000 of the labor force, while the stock of scientists moderately increased from 109 per 10,000 of the labor force in 1986 to 135 per 10,000 in 1991.

- Japan has more scientists and engineers engaged in R&D relative to its labor force than the United States. In 1993, Japan had 80 research scientists and engineers per 10,000 of the labor force, while in that same year U.S. researchers numbered 74 per 10,000 of the labor force.

Government R&D

- In the 1990s, the government is the dynamic growth sector of R&D in Japan. After a decade of stagnant funding throughout the 1980s, Japanese government support of R&D has increased 5.7 percent annually in real terms in the 1990s, from $9 billion in 1991 to $13 billion in the 1997 science budget authorization (in inflation-adjusted PPP dollars).[6] The Japanese government increased its share of overall R&D support from 16 percent in 1990 to 20 percent in 1994.

[6] The 1997 government science budget received Cabinet approval and awaits Diet approval.

- Japan's Cabinet Decision of 1992 called for doubling the government R&D budget as soon as possible. The Basic Plan for S&T of 1996 suggests that the government allocate 117 trillion yen (equivalent to approximately $74 billion in constant dollar terms) to R&D from 1996 to 2000, a 35-percent increase over the previous 5 years of government funding of R&D. In contrast, the 10-year trend for government-sponsored research in the United States has been a declining real budget. At the peak of public funding for research in 1987, the U.S. Government invested $57.9 billion. In preliminary data for 1997, U.S. Government investment decreased to $47 billion.

- Government-funded civilian R&D as a percent of GDP declined both in Japan and in the United States throughout the 1980s, followed by an increase in support of civilian R&D in the 1990s. However, from 1990–96, Japan had a higher annual rate of growth in its government budget for civilian research (5.9 percent) than the United States (1.5 percent). By 1996, Japanese government civilian R&D rose to 0.54 percent of GDP; that of the United States represented 0.40 percent of GDP.

- The Japanese government spends the largest portion of its R&D budget—an estimated 51 percent—on the general objective of "advancement of knowledge," which includes general university research funds (not to be equated with basic research). The second most important objective of Government R&D funding in Japan is energy research—approximately 21 percent. The U.S. Government funds the majority of its R&D budget on defense—55.3 percent in 1994—followed by health research at approximately 17 percent.

Industrial R&D

- Although government R&D budgets have recently increased, industrial laboratories still conduct the vast majority of Japan's research, funding nearly 75 percent of the total resources for R&D and employing nearly 70 percent of the research scientists and engineers.

- In both the United States and Japan, industrially funded R&D increased rapidly from 1975 to the peak year in 1991, followed by stagnant or slightly declining industrial R&D investments each year until 1994. This downward trend may have been reversed in the United States in 1995. Japanese industry investment in R&D rose from $11.4 billion in 1975 to $44 billion in 1991, representing an 8.9-percent average annual growth rate. In the peak year of industrial support of R&D, 1991, private industry accounted for 78 percent of overall R&D in Japan. Industrially supported research in Japan declined an average of 3.1 percent annually from 1991–94.

- As a percentage of gross domestic product (GDP), Japan's industrial R&D doubled from 1975–90, and declined slightly in the 1990's. In 1994, the ratio of overall Japanese industrial R&D to GDP—1.9 percent—was comparable to the U.S. proportion of 1.8 percent. However, Japanese industrial R&D is almost entirely (98 percent) financed by companies themselves. This Japanese company-funded R&D as a percentage of GDP has surpassed the U.S. ratio of company-funded R&D to GDP every year since 1975. In 1994, the ratio of company-funded R&D represented 1.9 percent of GDP for Japan and 1.5 percent for the United States.

- Japanese industrial R&D is enhancing its science base, and shifting among areas of concentration. For example, the proportion of R&D in the science-based, newer industries of drugs and medicines, computers, and electrical machinery has increased, and that in automotive industries, chemicals, and the basic metals industry of iron and steel has decreased.

- In both the United States and Japan, the number of industrial scientists and engineers increased at an average annual rate of growth greater than 5 percent throughout the 1980s. However, Japanese industry continued to increase employment of R&D scientists and engineers despite the economic recession in the 1990s. In the United States, industry decreased the number of scientists and engineers employed in R&D by about 25,000 from 1992–94.

- Japan has more R&D scientists and engineers (RSEs) per 10,000 employees in manufacturing companies than the United States. In 1993, Japan employed 622 RSEs per 10,000 employees in manufacturing companies, compared with 520 in the United States that same year. The higher employment of RSEs in manufacturing companies in Japan has existed since 1985.

Higher Education

- With a population that is less than one-half that of the United States, Japan produced more than 91,000 engineering degrees in 1994 compared with approximately 63,000 in the United States. Some of this disparity stems from the difference in taxonomies used in higher education: faculties of computer science and solid-state physics are included in engineering in Japanese universities. Albeit with a broader definition of engineering, Japanese undergraduate students earn 20 percent of their degrees in engineering fields,[7] far greater than the 5 percent of students in the United States who earn their undergraduate degree in engineering. Relative to the size of its population, Japan has three times more engineers earning university degrees and entering the labor force than the United States.

- Few students in Japan earn degrees in natural science fields at the undergraduate level. Only 3.5 percent of the undergraduate degrees in Japan are earned in natural sciences (physical, environmental, and biological sciences), and 2.9 percent are earned in agricultural sciences. In the United States, 9.3 percent of all undergraduate degrees are earned in the natural sciences, and 1.1 percent are earned in agricultural sciences.

- Graduate S&E programs, traditionally small in Japan, have begun to expand. Graduate enrollment in S&E fields increased from 31,000 in 1975 to more than 91,000 in 1994. Even with the recent expansion, however, Japanese graduate enrollment in all S&E fields was still small compared with the 433,000 graduate S&E students enrolled in U.S. universities. Particularly small are Japanese graduate programs in the natural sciences (12,000 graduate students in Japan versus 120,000 in the United States). Relative to its size, Japan's graduate enrollment in natural sciences is about one-quarter those of the United States. In contrast, engineering graduate programs in Japan have comparable enrollment to those in the United States (relative to the size of its population).

- Until recently, most doctorates in natural sciences and engineering in Japan were earned by industrial researchers after many years of research within Japanese companies. With the expansion of university-based doctoral programs, however, the proportion of these degrees earned is decreasing. By 1994, more doctoral engineering degrees were earned for research within university laboratories (53 percent) than for those within industrial research laboratories (47 percent).

Foreign Students

- The majority of foreign students in Japan are at the undergraduate level. In 1994, only 17,800 of the 50,000 foreign students in Japan were studying at the graduate level. By contrast, almost one-half of the 425,000 foreign students in the United States in that same year were studying at the graduate level. Of approximately 191,800 students who came to the United States for graduate studies in 1994, almost one-half were pursuing degrees in the natural science and engineering fields. Likewise, more than one-half of the foreign graduate students in Japan were in S&E fields.

- In 1992, foreign students earned 37 percent of engineering doctoral degrees within Japanese universities and 25 percent of natural science doctoral degrees. By contrast, in U.S. universities foreign students earned slightly more than 50 percent of the engineering doctoral degrees and one-third of the natural science doctoral degrees in 1993.

Academic R&D

- The decade-long trend, observed from 1980–91, to a diminishing role for academic performers in total Japanese research and development ended in 1992. In that period, academic performance decreased from a 17-percent share to a 12-percent share of

[7] Japan's percentage is similar to the proportion of engineering degrees in Singapore, Korea, and Taiwan. Only China has a considerably higher concentration on engineering: 40 percent of Chinese undergraduates study engineering (NSF, 1993).

total Japanese R&D performance. As a result of strong support provided by the government's 1993 and 1994 budgets, Japan's academic performance rose to a 14-percent share of total Japanese R&D.

- In the 1990s, Japan's Ministry for Education, Science, Sports and Culture (Monbusho) has increased university research funding through competitive grants-in-aid. In addition, after 1995 government agencies other than Monbusho have been contributing directly to academic science. Monbusho has recently written legislation to allow direct funding of university researchers by other science agencies: the Science and Technology Agency (STA) and the Ministry of International Trade and Industy (MITI). The majority of university research funding, however, still comes from Monbusho's formula funding of university chairs.

- By 1996, about 6,000 Japanese graduate students and postdoctorates had some government funds. The target is to fund about 10,000 government fellowships by the year 2000. The ability of faculty and national laboratories to hire postdoctorate researchers and research assistants contributes to the expansion of the universities' capacity for conducting basic research.

- The Japanese government, under Monbusho and STA funding, is supporting cutting-edge facilities and is a contributing member of the European Center for Nuclear Research (known by its French initials, CERN) for international cost-sharing. Monbusho's support of new world class facilities and "big science" will allow the expansion of basic science in the fields of astronomy, high energy physics, space science, environmental earth science, and bioscience.

Outputs and Impacts

- Japan's goal of increasing its international cooperative research, as stated in S&T White Papers since the mid-1980s, has resulted in increased international coauthorship in its scientific literature. During the 1988–93 period, almost 11 percent of Japan's scientific articles in this set of journals were internationally coauthored, up from 7 percent in the previous period of 1981–87. While U.S. scientists are still the main collaborators on internationally coauthored articles with Japanese scientists (43 percent), an increasing percentage of Japan's internationally coauthored articles are based on collaborations with scientists from European (34 percent) and Pacific Rim (14 percent) countries, particularly China.

- Japan's strong growth in industrial R&D throughout the 1980s corresponds with similar strong increases in the number of patents during the same period. From 1980–90, the number of U.S. patents granted to Japanese scientists and engineers increased at an average annual rate of 10.6 percent—from 7,000 in 1980 to 19,524 in 1990. Despite a recent slowing in patent growth rate, Japanese inventors still received about 23 percent of all U.S. patents in 1993 and represented almost half of all foreign patents granted in the United States, indicating a strong level of inventiveness.

- While Japan has traditionally been a net importer of technological know-how, data for 1990 show Japanese manufacturing industries' trade in technological know-how nearly in balance in 1990. By 1993, Japanese companies received more royalties and fees than they paid for technological know-how in several industry fields, including industrial chemicals, ceramics, iron and steel, and fabricated metals. Additionally, in motor vehicles, the ratio of receipts to payments was 14 to 1, reflecting the spread of Japanese know-how in automobile manufacturing in Europe and Asia.

- In 1994 U.S.–Japan bilateral trade, Japan's export of advanced technology products reached more than $28 billion (exceeding imports from the United States by more than $14 billion), indicating that Japan is strong in the creation of such industrial output. The largest trade surpluses for Japan are from computers and telecommunications and electronics. The largest deficits for Japan from high technology trade with the United States result from aerospace and nuclear technology, and increasingly, from software.